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Estimating Decay in 40- to 90-Year-Old Grand Fir Stands in the Clearwater Region of Northern Idaho

Gregory M. Filip, John W. Schwandt, and
Susan K. Hagle

Authors

GREGORY M. FILIP is a research plant pathologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory, 1401 Gekeler Lane, La Grande, Oregon 97850; JOHN W. SCHWANDT is a forest pathologist, Idaho Department of Lands, P.O. Box 670, Coeur d'Alene, Idaho 83814; and SUSAN K. HAGLE is a plant pathologist, U.S. Department of Agriculture, Forest Service, Forest Pest Management, P.O. Box 7669, Missoula, Montana 59820.

Abstract

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The fir decay equation for Oregon and Washington was used to predict stem decay in 12 grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) stands in the Clearwater region of northern Idaho. These 12 stands represented a range in geographic and stand characteristic variation. All 12 observed decay percentages were within their associated 95-percent prediction intervals. We therefore concluded that the fir decay equation for Oregon and Washington can be used to estimate stem decay in 40- to 90-year-old grand fir stands in the Clearwater region. Information also is presented on decay biology, hazard-rating techniques, and stand management recommendations.

Keywords: Heartrot, grand fir, decay, hazard rating.

Summary

In 1988, 237 grand fir trees (*Abies grandis* (Dougl. ex D. Don) Lindl.) were sampled in 12 stands on the Clearwater National Forest and State of Idaho lands in northern Idaho. Information recorded for each tree included size, age, and the size, age, and height above ground for each wound present. Trees were felled, measured for volume, and dissected to determine presence and extent of incipient and advanced decay. The 12 stands sampled in northern Idaho were either western redcedar (*Thuja plicata* Donn ex D. Don) or grand fir habitat types, whereas 23 stands sampled in Oregon and Washington in 1983 to develop a fir decay equation were either grand fir or white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) habitat types. The 237 trees sampled in Idaho were slightly younger (68 vs. 77 years) but larger (7.6 vs. 5.9 inches in diameter at breast height) than the 464 trees sampled in Oregon and Washington. Trees in Idaho stands had lower live crown ratios (65 vs. 75 percent), less current radial increment (0.65 vs. 0.99 inch), less wounding (46 vs. 52 percent), and less decay (1.0 vs. 2.2 percent) than those in Oregon and Washington stands.

Wounds in Idaho stands were generally younger (17 vs. 20 years) and smaller (0.5 vs. 0.7 square foot) than wounds in the Oregon and Washington stands. Most of the wounds in Idaho stands were on the trunk, and many were frost cracks. Most of the wounds in the Oregon and Washington stands were located below 4.5 feet but not in contact with the soil.

To determine the applicability of the fir decay equation for Oregon and Washington to northern Idaho, the observed decay percentages from the 12 Idaho stands were compared to their associated 95-percent prediction intervals. Although observed decay values were slightly lower than predicted values, in all cases the observed decay values fell within the 95-percent prediction intervals. We conclude that the fir decay equation for Oregon and Washington can be used to estimate decay in 40- to 90-year-old grand fir stands in the Clearwater region of Idaho.

Only two sampled trees in one Idaho stand had conks of the Indian paint fungus (*Echinodontium tinctorium* (Ell. & Ev.)). These trees were 70 and 85 years old, and both had major trunk wounds. Considerable decay was associated with both trees: 24 and 32 percent of the merchantable cubic volume.

Seven trees in five stands were identified as having root disease caused by either *Armillaria* spp. or *Heterobasidion annosum*. Additional trees probably had root disease, but root decay fungi were not cultured or identified in most cases because the study was not designed to identify root disease. Infections caused by *Armillaria* spp. usually appeared as basal wounds with intact bark. In most cases, presence of *Armillaria* spp. was not detected until trees were felled and stumps were examined.

Information is also presented on decay biology, stand sampling, use of the fir decay equation, and managing stands to reduce decay.

Contents

Decay Fungi Biology and Damage

Damage From Decay Fungi

Grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) is a major species in many forests of the interior West. Many former stands of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and western white pine (*P. monticola* Dougl. ex D. Don) have gradually changed to fire-intolerant stands of grand fir and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) as a result of an 85-year-old fire-exclusion policy (Arno 1980, Gruell and others 1982) and past cutting practices that left grand fir and Douglas-fir and harvested the more valuable pines. Losses from decay are often severe in old-growth grand fir (Aho 1977, Hobbs and Partridge 1979). Decay in mature stands is caused primarily by the Indian paint fungus, *Echinodontium tinctorium* (Ell. & Ev.), and decay in younger firs is caused more commonly by the annosus root rot fungus, *Heterobasidion annosum* (Fr.) Bref.; *Pholiota limonella* (Pk.) Sacc.; *Hericium abietis* (Weir ex Huber) K. Harrison; and *Stereum sanguinolentum* (Alb. & Schw. ex Fr.) Fr. (Aho 1977, Aho and others 1987, Maloy and Gross 1963). Fungi that cause laminated root rot, *Phellinus weirii* (Murr.) Gilbertson; armillaria root disease, *Armillaria ostoyae* (Romagn.) Herink; and *H. annosum* cause severe mortality of grand fir in Oregon and Washington (Filip and Goheen 1984) and in Idaho and Montana (Hagle and Goheen 1988). Armillaria root disease is common in grand fir on the Clearwater National Forest (James and others 1984, Stewart and others 1982).

Biology of the Indian Paint Fungus

Although several coniferous species may serve as hosts for the Indian paint fungus, damage is greatest in grand fir in northern Idaho. The life cycle of the Indian paint fungus is illustrated in figure 1. The most conspicuous sign of the Indian paint fungus is the sporophore or conk, which is large and woody with a black, cracked upper surface; a gray-toothed lower surface; and a brick-red interior. The red interior was used by American Indians for paint (Gilbertson 1980), hence the common name.

Spores are produced by the conks throughout the year in British Columbia (Etheridge and Craig 1976); however, optimal conditions for sporulation and germination occur in spring and fall when temperatures periodically fall below 40 °F and mean daily temperatures range from 40 to 60 °F. Low temperature rather than moisture is the major activating factor. High levels of humidity in the air are not required for sporulation except at temperatures above 40 °F.

Spores of the Indian paint fungus do not infect wounded tissues or old branch stubs as was once thought. Spores infect small (less than 0.1 inch in diameter) exposed branchlet stubs just before these stubs are overgrown (Aho and Hutchins 1977, Etheridge and Craig 1976). These stubs form when dead branchlets less than 0.1 inch in diameter break off at their base, thereby exposing presumably sterile wood to infection. A minimum of 40 years is necessary for branchlets to die and break off. Suppressed and slowly growing trees or branches heal these branchlet stubs very slowly, thus allowing more time for infection by Indian paint fungus spores. Suppressed branches also have more shade-killed branchlets and thus produce more branchlet stubs or potential infection courts. Branchlet stubs heal rapidly on vigorously growing trees or branches.

After spores have germinated, fungal growth continues to develop within the branch until branchlet stubs are overgrown with wood. Once branchlet stubs are overgrown, the fungus becomes dormant and forms a resting spore (chlamydospore) that can survive for 50 or more years without causing decay.
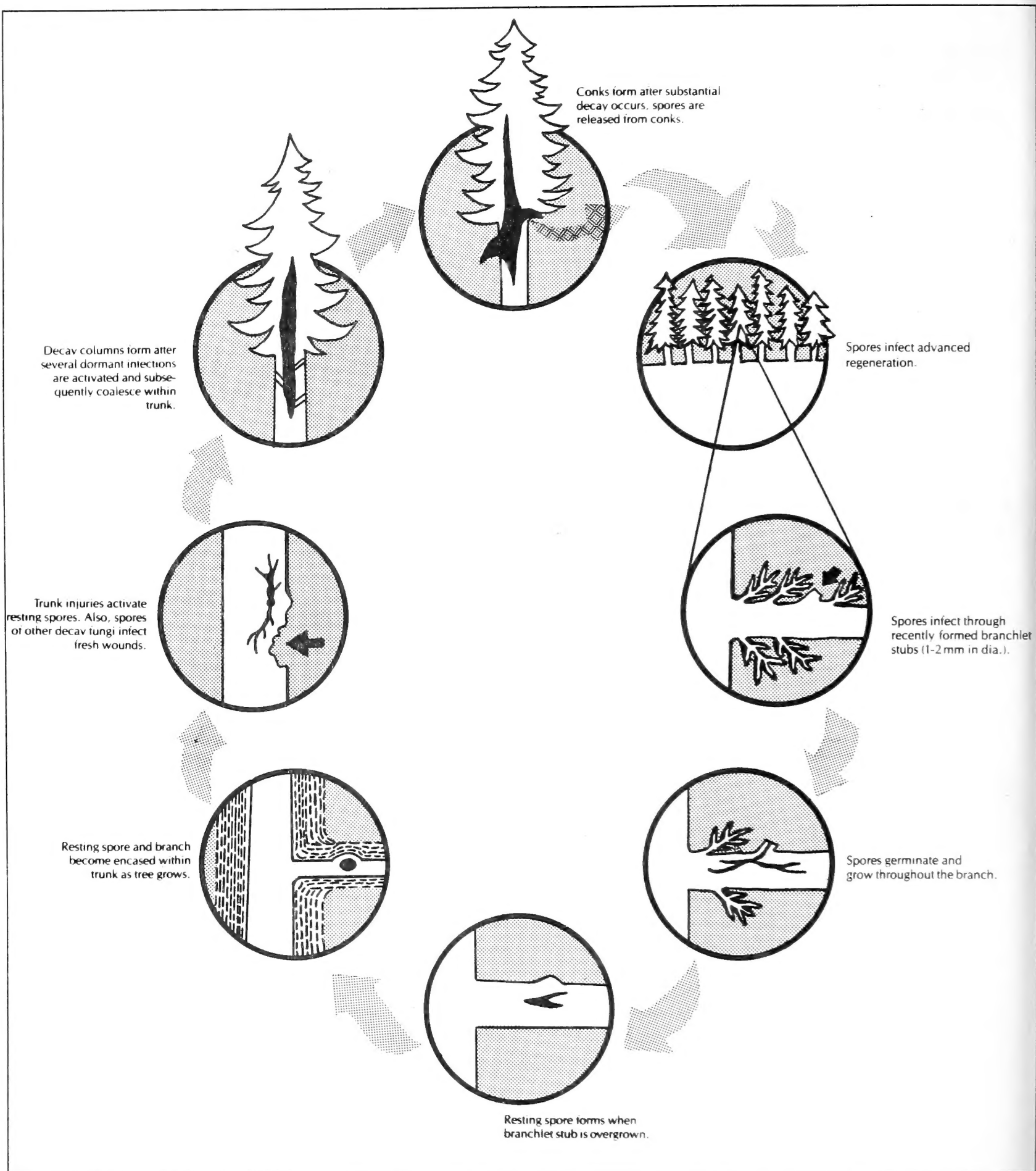
Conks form after substantial decay occurs, spores are released from conks.

Spores infect advanced regeneration.

Spores infect through recently formed branchlet stubs (1-2 mm in dia.).

Decay columns form after several dormant infections are activated and subsequently coalesce within trunk.

Trunk injuries activate resting spores. Also, spores of other decay fungi infect fresh wounds.

Spores germinate and grow throughout the branch.

Resting spore and branch become encased within trunk as tree grows.

Resting spore forms when branchlet stub is overgrown.

Figure 1—Life cycle of the Indian paint fungus.

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Dormant infections are reactivated by mechanical injuries, frost cracks, or formation of large branch stubs that allow air to enter the trunk interior. Wounds must be within 1 foot of dormant infections to reactivate the fungus (Aho and others 1987). Even the smallest wounds, including attacks by fir engraver beetles (*Scolytus ventralis* LeConte), can activate dormant infections. But several factors determine the amount of subsequent decay, and the larger the injury, the more likely that one or more dormant infections will be activated and cause decay.

Although a single suppressed tree may have several infections, relatively few cause trunk decay because (1) infections need to be within the trunk (trunk-encased branches) or immediately adjacent to the trunk in branches, (2) most infections become dormant and are not activated because wounding is too far from infections, and (3) infections probably do not survive after branch death except in branches encased within the trunk.

Reactivated infections first cause elongated areas that are stained light brown or yellow. At this incipient stage, the structural properties of the wood are not visibly altered, but affected wood is unsuitable for many uses, even in the earliest stages of decay (Maloy 1967). Advanced decay, which appears yellow to reddish-yellow and fibrous or stringy, is the culmination of prolonged fungus attack. Extensive heartrot columns occur after several dormant infections have become active, caused decay, and coalesced.

After extensive decay has formed, conks are produced, often at old branch stubs and occasionally at wounds where the fungus has a continuous pathway from the interior to the outside of the tree. Spores can be produced for several years after conks have formed. Spores also may be produced for at least 10 years on trees that have died or been felled (Maloy 1967). Felled trees produce more conks than do standing dead trees. Conk survival is poorer on trees bucked into logs than on felled but intact trees. The percentage of conks surviving on moderately to heavily shaded logs is twice that on lightly shaded logs (Maloy 1967).

Biology of Other Decay Fungi

Other decay fungi (including *H. annosum*, *Stereum sanguinolentum*, *Pholiota limonella*, and *Hericium abietis*) besides the Indian paint fungus infect grand fir by means of spores released from conks or mushrooms. Spores infect fresh wounds and, in some cases, follow a succession of other microorganisms such as bacteria, yeasts, and nondecay fungi. More decay is associated with larger, older wounds in contact with the soil where moisture conditions are favorable for decay development. Conks or mushrooms appear after advanced decay develops. There is some evidence that *H. abietis* may infect through branchlet stubs and become activated by wounds in a way similar to the Indian paint fungus (Aho and others 1987).

Fungi, such as *A. ostoyae* and *Phellinus weirii*, causing root and butt rots in grand fir infect by underground spread of mycelia across root contacts and grafts. Aerial infection by spores is negligible, hence wounds are not necessary for infection. *Heterobasidion annosum* infects both through root contacts and by spores through fresh wounds.

The condition known as wetwood is extremely common in grand fir (Ward and Pong 1980) and resembles early stages of decay. Wetwood is a type of heartwood, usually occurring at the base of standing trees, that has been infused internally with water. The exact cause of wetwood is uncertain but has been attributed to several factors: microbial (bacteria), nonmicrobial (injury), and normal age-growth formation. Wetwood is not incipient decay and will not become advanced decay. There is some evidence that wetwood actually inhibits decay caused by fungi such as *H. annosum* (Worrall and Parmeter 1982). Wetwood can cause substantial economic loss when affected timber is converted into logs and products by causing shake, collapse, honeycomb, ring failure, warpage, and slower drying rates.

Generalizations About Decay

The following generalizations apply to decay from all fungi in grand fir in the interior West:

1. Trees compartmentalize decay; that is, decay columns will not exceed the diameter of the tree at the time wounding occurred unless additional wounding takes place (Shigo and Marx 1977).

2. Amount of decay in a stand increases from upper slope to lower slope (Maloy 1967); moisture conditions are more favorable for infection and decay at lower slopes, especially in riparian zones.

3. Amount of decay is greater on northern vs. southern aspects; moisture conditions are more suitable for infection and decay development on northern aspects (Aho and others 1987).

4. Amount of decay increases proportionally with stand age and diameter where diameter is directly proportional to age (Aho 1977).

5. Amount of decay increases proportionally with frequency of tree wounding in the stand (Filip and others 1983).

6. Amount of decay increases with wound size and age; also, basal wounds have more decay than upper stem wounds, age and size being constant (Aho 1977, Shigo and Marx 1977).

7. Amount of decay is influenced by tree genetics; some trees within a species are more resistant to decay than others (Shigo 1985).

8. Decay may be caused by a single species of fungi, but infections by two or more species are common (Aho 1977).

9. Amount of basal decay (butt rot) is influenced by the distribution and species of root pathogens on the site (Filip and Goheen 1984).

The Fir Decay Equation

In 1983, an equation was developed to predict the amount of stem decay in stands of advance grand and white fir regeneration in Oregon and Washington (Filip and others 1983). Percentage of cubic volume of decay (DV%) by stand is a function of (1) mean stand age (AG), (2) percentage of crop trees with wounds (WD%), and (3) stand aspect (AS), where

$$LogN(DV\%) = 1.8219\ LogN(AG) + 0.8386\ LogN(WD\%) - 0.4151(AS) - 10.4222\ .$$

$$(R^2 = 0.70)$$

Although the equation has been tested only in southern Oregon (Goheen and others 1985), it is frequently used by forest pathologists and silviculturists for interior mixed-conifer stands in Oregon and Washington. The equation has been neither widely used nor tested on grand fir in other states. The objective of this study was to test the ability of the fir decay equation for Oregon and Washington to predict the percentage of stem decay in several stands of grand fir in the Clearwater region of northern Idaho. A second objective was to present a set of guidelines for forest managers to use in estimating, predicting, and preventing decay in managed grand fir stands in the Clearwater region.

Study Methods

Stand and Tree Selection

In Idaho, we used methods similar to those used to develop the fir decay equation in Oregon and Washington (Filip and others 1983). All sampled stands were on either State of Idaho or USDA Forest Service (Clearwater National Forest) lands. Stands in the Clearwater National Forest were selected from the Forest Timber Inventory Data Base by querying for all stands having the following characteristics: (1) stands dominated by grand fir and (2) mean stand age of 40 to 100 years. From the master list of stands, two stands were selected and sampled from each of the four Ranger Districts in the Clearwater National Forest. This selection was based on (1) proximity of stands to main roads, (2) amount of stem wounding (light and heavy), and (3) stand age (young and old). Two stands were selected and sampled from State of Idaho lands with the help of local forest managers. Selected stands were representative of stands of grand fir that potentially will be managed in the Clearwater region.

The following stand information was requested from the database and was confirmed in the field:

1. Primary overstory species (by basal area)
2. Aspect (N, NE, E, SE, S, SW, W, or NW)
3. Elevation
4. Habitat type
5. Stand age

In August 1988, one or two parallel transects, 3 to 5 chains apart, were used to sample each of the 12 stands. One potential crop tree, distinguished by height and form but not necessarily absence of wounds, was selected that was nearest to sample points located every chain along transects. Trees with conks were avoided. Twenty trees per stand were selected. Only potential crop trees were selected because it was assumed that noncrop trees will be destroyed during stand improvement.

Information collected from each tree before felling included:

1. Diameter at breast height (d.b.h.; at 4.5 feet, to the nearest 0.1 inch).
2. Number of wounds greater than or equal to 1 square inch, including sealed wounds.
3. Wound type (root, basal, below 4.5 feet, above 4.5 feet, top break, frost crack).
4. Wound height (groundline to bottom of wound, to the nearest 0.1 foot).
5. Wound size (length × width × 0.75, to the nearest 0.1 foot).
6. Number and type of conks.

Tree Dissection and Data Analysis

Each tree was felled and initially bucked at 4.5 feet, top of each 16-foot log, 4-inch top, and at each wound or conk. The following information was then collected:

1. Total height (groundline to tip, nearest 0.1 foot).
2. Merchantable height (stump top to 4-inch top).
3. Distance from groundline to the first major live branch where it joins the stem.
4. Mean diameter inside bark (d.i.b.) at stump (nearest 0.1 foot).
5. Mean d.i.b. at top of each 16-foot log.
6. Mean d.i.b. at 4-inch top.
7. Total age (at stump).
8. Age at 4.5 feet.
9. Wound age (see description below).
10. Last 10-year radial growth (mean of two perpendicular radii at 4.5 feet, nearest one-twentieth of an inch).

Live crown ratio was calculated by subtracting height to the first branch from total tree height and dividing the result by the total tree height multiplied by 100. Wound age was determined by dissecting wounds and counting annual rings in wood formed since wounding occurred. Decay columns associated with visible wounds were recorded by wound number. Decay columns not associated with visible wounds were recorded by distance from the ground line to the near end of the decay column. Buried wounds were recorded if detected. Presence of root disease, as manifested by butt decay, was recorded for each tree.

Each decay column was dissected. Diameters of the large and small ends and length (nearest 0.1 foot) of each decay column (advanced and incipient) were measured. Columns of wetwood were not measured because amount of wetwood was not used to develop the original equation.

The cubic-foot volume of each tree and of decay was determined from Smalian's formula, $(A + a)/2 \times L$ where A = the cross-sectional area at the large end, a = the cross-sectional area at the small end, and L = length. The percentage of cubic-foot decay for each tree was calculated by dividing the total cubic-foot volume of decay in each tree by the merchantable cubic-foot volume of the tree (stump to 4-inch top) multiplied by 100. Total stand decay (crop trees) was the mean of the percentage of decay for all sampled crop trees in the stand. Defect, including decay, shake, check, and frost cracks, is measured only in board-foot calculations and was not measured in this study.

Because collecting and processing decay samples for fungus identification is time consuming and because several investigators have already reported the incidence of stem decay fungi in grand fir in Idaho (Hobbs and Partridge 1979, Hudson 1972, Maloy and Robinson 1968), we did not collect decay samples but concentrated our efforts on sampling decay incidence and extent in as many stands as possible in the available time.

The validity of the Oregon and Washington fir decay equation was tested by determining if the decay values observed in the 12 Idaho stands were within their associated 95-percent prediction intervals. A confidence interval is an interval for the mean value of the response, whereas a prediction interval is the mean value plus error. Prediction intervals were calculated by using the SAS/STAT package, version 6 (SAS Institute Inc. 1987).

Regression analysis was used to develop relations between the dependent variable (percentage of decay [stand basis]) and the independent variables (wound age, wound size, and wound height).

Study Results

Comparisons Between Idaho Stands and Oregon and Washington Stands

Stand, tree, and wound characteristics are shown in tables 1, 2, and 3. The 12 stands sampled in northern Idaho were either western redcedar or grand fir habitat types, whereas the 23 stands sampled in Oregon and Washington in 1983 to develop the fir decay equation were either grand fir or white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) habitat types. The 237 trees sampled in Idaho were slightly younger (68 vs. 77 years) but larger (7.6 vs. 5.9 inches d.b.h.) than the 464 trees sampled in Oregon and Washington. Idaho stands had lower live crown ratios (65 vs. 75 percent), less current radial increment (0.65 vs. 0.99 inch), less wounding (46 vs. 52 percent), and less decay (1.0 vs. 2.2 percent) than the Oregon and Washington stands. Wounds in Idaho stands were generally younger (17 vs. 20 years) and smaller (0.5 vs. 0.7 square foot) than wounds in the Oregon and Washington stands. Most of the wounds in Idaho stands were on the trunk, and many were frost cracks. Most of the wounds in the Oregon and Washington stands were located below 4.5 feet. There was no correlation between percentage of tree decay and wound size, wound age, or wound height by stand in Idaho stands or Oregon and Washington stands.

Incidence of Conks and Root Disease

Although our selection process biased our sample to trees without conks, two sampled trees in one stand had conks of the Indian paint fungus. These trees were 70 and 85 years old, and both had major trunk wounds. Considerable decay was associated with both trees: 24 and 32 percent of the merchantable cubic volume.

Root disease caused by either *Armillaria* spp. or *Heterobasidion annosum* was found in seven crop trees in five stands. Probably more trees had root disease, but root decay fungi were not cultured or identified in most cases because the study was not designed to identify root disease. Infections caused by *Armillaria* spp. usually appeared as basal wounds with intact bark. In most cases, presence of *Armillaria* spp. was not detected until trees were felled and stumps were examined.

Table 1—Site characteristics and decay estimates for 12 grand fir stands in the Clearwater region of northern Idaho

Stand name and number	Legal description	Habitat type[a]	Elev.	Aspect	Total age	Trees with wounds[b]	Current observed decay	Current estimated decay	95-percent prediction interval
			Feet		Years	-------------Percent------------			
Powell 403	T. 36 N., R. 2 E., sec. 11, 12	ABGR/ASCA	3200	S	77	45	1.0	1.3	.2-6.6
Powell 719	T. 37 N., R. 13 E., sec. 25, 26	ABGR/CLUN	3600	W	73	50	1.6[c]	2.0	.4-10.4
Palouse 16-17	T. 43 N., R. 3 W., sec. 36	THPL/ADPE	3100	S	84	45	.4	1.5	.3-7.7
Palouse 13	T. 43 N., R. 3 W., sec. 25	THPL/CLUN	3300	S	86	15	.6	.6	.1-3.3
Pierce 40	T. 35 N., R. 6 E., sec. 10	THPL/CLUN	3400	W	61	45	.8	1.3	.2-7.0
Pierce 208	Tps. 35, 36 R. 6 E., sec. 2, 3, 34, 35	THPL/ASCA	4000	S	80	60	.3	1.8	.3-9.1
Lochsa 37	T. 33 N., R. 6 E., sec. 29	THPL/CLUN	2800	SE	72	25	.9	.7	.1-3.6
Lochsa 28	T. 33 N., R. 6 E., sec. 27	ABGR/CLUN	3600	W	72·	20	.7	.9	.2-4.8
North Fork 08	T. 38 N., R. 5 E., sec. 3, 4	ABGR/CLUN	3200	Flat	44	40	1.2	.6	.1-3.7
North Fork 89	T. 39 N., R. 6 E. sec. 5, 6, 7, 8	THPL/CLUN	3400	N	79	30	.8	1.6	.3-7.8
Idaho-Space	T. 36 N., R. 5 E., sec. 32	THPL/CLUN	3000	SW	45	40	1.2	.4	.1-2.3
Idaho-Ford	T. 35 N., R. 4 E., sec. 9	THPL/CLUN	3000	Flat	50	10	.1	.3	.1-1.5

[a] ABGR = Abies grandis, ADPE = Adiantum pedatum, ASCA = Asarum caudatum, CLUN = Clintonia uniflora, THPL = Thuja plicata.

[b] Trees with wounds older than 10 years.

[c] 2 trees with conks were removed for decay calculations.

Table 2—Means of tree attributes for 12 grand fir stands sampled in the Clearwater region of northern Idaho

Stand name and number	No. of trees	Total age (Years)		Last 10 year radial growth (Inches)		Live crown ratio (Percent)		D.b.h. (Inches)		Total height (Feet)		Merch. volume per tree (Cubic feet)		Volume decayed (Percent)	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Powell 403	20	77	50-110	0.35	0.05-1.25	58	32-84	7.1	5.9- 9.1	58.5	31.6- 80.4	6.9	2.8-16.0	1.0	0-15.8
Powell 719	20	73	54- 85	.30	.10-1.00	65	10-88	6.7	5.4- 9.6	51.7	36.1- 71.7	6.1	2.5-13.1	3.9[a]	0-32.4
Palouse 16-17	20	84	72- 94	.40	.10-1.25	61	35-83	6.9	4.7-10.2	48.2	27.0- 78.5	6.0	1.6-17.1	.4	0- 3.4
Palouse 13	20	86	61- 97	.45	.05-0.95	68	39-86	6.7	4.2- 8.4	51.8	27.0- 76.2	5.7	.4-13.9	.6	0- 8.6
Pierce 40	20	61	39-108	.80	.10-1.40	72	29-91	7.4	5.0-10.1	49.7	32.8- 65.6	5.9	1.6-12.9	.8	0-11.6
Pierce 208	18	80	68- 91	.50	.10-1.15	58	32-86	9.1	4.7-19.2	67.1	32.0-101.6	17.4	2.5-61.2	.3	0- 2.9
Lochsa 37	20	72	45-118	.75	.15-2.00	60	30-85	8.3	5.3-11.5	61.3	42.8- 74.7	9.2	2.3-17.5	.9	0-15.5
Lochsa 28	20	73	29-157	.90	.25-1.80	77	43-92	7.4	4.5-11.8	49.0	22.5- 70.2	6.0	.8-12.8	.7	0- 9.0
North Fork 08	20	44	39- 52	1.20	.60-1.95	83	54-96	8.9	5.5-14.5	41.9	21.7- 66.0	8.3	2.0-31.7	1.2	0-10.5
North Fork 89	19	79	42-170	.60	.20-1.60	67	42-83	8.4	4.5-15.0	55.8	23.0- 97.7	11.9	.7-48.2	.8	0-10.2
Idaho-Space	20	45	41- 52	1.05	.60-1.60	72	55.85	7.8	5.5-11.7	58.2	33.9- 78.0	9.4	1.9-42.5	1.2	0-19.7
Idaho-Ford	20	50	42- 55	.55	.25- .95	45	30-62	6.4	4.8- 8.1	54.8	35.3- 67.3	5.5	1.5- 9.0	.1	0- 0.5
Average	237	68	44- 86	.65	.30-1.20	65	45-83	7.6	6.4- 9.1	53.9	41.9- 67.1	8.1	5.5-17.4	1.0	.1- 3.9
Average [b]	464	77	43-115	.95	.45-1.45	75	61-85	5.9	3.6- 7.8	31.3	18.2-45.5	3.4	.4- 7.8	2.2	.1- 6.0

[a] Includes 2 trees with conks

[b] Averages for Oregon and Washington study

Table 3—Characteristics of 187 wounds sampled on 107 grand fir trees in 12 stands in the Clearwater region of northern Idaho

Stand name and number	Trees with wounds	No. of wounds	Wound age		Wound size		Wound height		Wound type[c]					
			Mean	Range	Mean	Range	Mean	Range	1	2	3	4	5	6
	Percent		Years		Square feet		Feet		-------Percent-------					
Powell 403	45	23	26	0-64	.5	0-3.7	12.4	0-45.7	0	13	44	26	4	13
Powell 719	50	14	17	0-29	.5	0-1.2	7.8	0-20.2	0	30	21	21	14	14
Palouse 16-17	50	11	30	1-51	.3	0- .9	3.0	0-12.0	0	9	27	9	0	55
Palouse 13	50	14	8	1-28	.7	0-1.5	4.8	.4-16.7	0	14	43	36	0	7
Pierce 40	50	13	25	5-56	.3	0-2.4	9.0	.5-29.3	0	0	38	46	8	8
Pierce 208	78	25	20	0-54	.6	0-5.0	14.4	0-60.0	4	4	20	24	8	40
Lochsa 37	40	19	15	1-38	.2	0- .8	16.0	0-63.7	0	16	21	47	5	11
Lochsa 28	25	13	19	0-35	.5	0-2.4	6.0	0-23.0	8	0	31	15	0	46
North Fork 08	40	11	8	0-15	.6	0-1.3	6.4	.6-31.2	9	9	27	18	0	37
North Fork 89	42	16	16	1-34	.4	0-2.1	10.7	0-23.4	6	0	6	38	0	50
Idaho-Space	45	17	13	0-23	1.0	0-8.6	11.0	0-58.9	0	6	35	6	0	53
Idaho-Ford	35	11	9	3-23	.8	0-6.0	16.8	.7-48.9	0	9	27	46	18	0
Average	46	187	17	8-30	.5	.2-1.0	10.6	3.0-16.8	2	9	28	28	5	28
Average[b]	52	334	20	8-35	.7	.2-2.0								

[a] 1=root wound; 2=basal wound; 3=wound below 4.5 feet.; 4=wound above 4.5 feet.; 5=top break; 6=frost crack
[b] Average for Oregon and Washington study

Equation Testing

The fir decay equation for Oregon and Washington overestimated the amount of decay in 8 of 12 stands, underestimated decay in 3 stands, and gave the same estimate for one stand (table 1). All 12 observed decay values were within their associated 95-percent prediction intervals (fig. 2). We therefore conclude that the fir decay equation for Oregon and Washington can be used in the Clearwater region of northern Idaho to reliably estimate amount of stem decay in 40- to 90-year-old grand fir stands. The following section explains how to sample stands and use the equation to estimate decay.
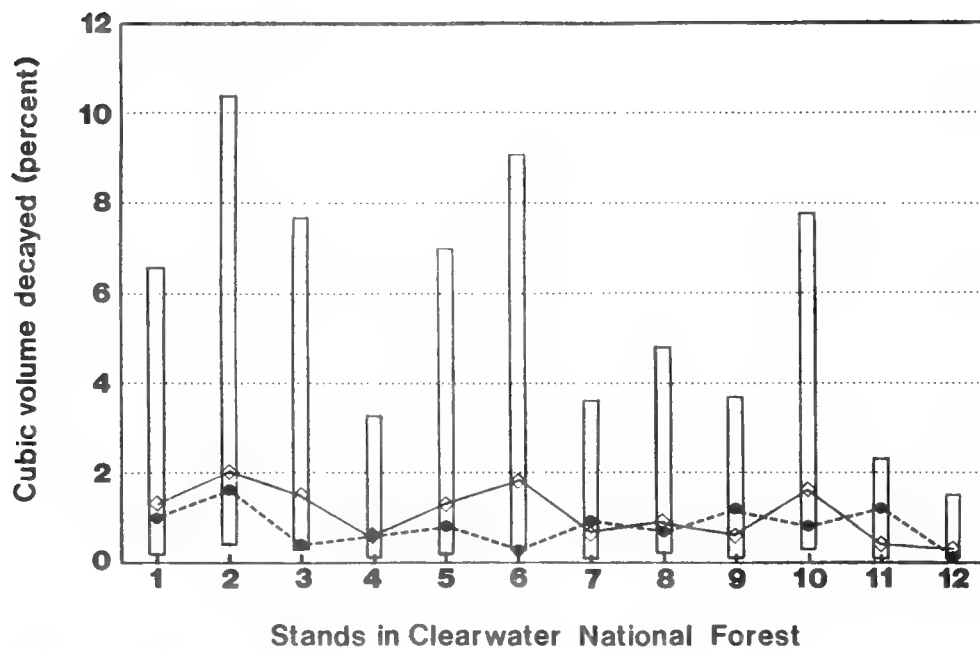
Figure 2—Prediction intervals (bars) of the fir decay equation
for 12 stands of grand fir in northern Idaho. Stars within bars
represent actual decay volumes for each stand; diamonds
within bars represent estimated decay volumes for each stand.

Decay-Estimating Method

Decay Equation

The following equation can be used to estimate the percentage of crop tree volume (in cubic feet) with both incipient and advanced decay caused by all decay fungi including *H. annosum*, *Pholiota limonella*, *Hericium abietis*, *Armillaria* spp., and *Stereum sanguinolentum* as well as *E. tinctorium*, the primary cause of decay:

$$LogN(DV\%) = 1.8219 \, LogN(AG) + 0.8386 \, LogN(WD\%) - 0.4151(AS) - 10.4222 \, ,$$

where   LogN = natural logarithm,
              DV% = percentage of total crop tree volume with incipient and advanced decay,
              AG   = mean crop tree total age (in years),
              WD% = percentage of crop trees with one or more wounds, and
              AS   = stand aspect (0 = N, NW, NE, W, or flat; 1 = S, SE, SW, or E).

$$(R^2 = 0.70, \, SE = 0.79)$$

This equation can be programmed on hand-held calculators or data recorders.

Stand Sampling Procedures

Depending on stand shape, follow one or more parallel transects through the stand and select one potential crop tree (based on height, form, live crown ratio, and absence of wounding and conks) nearest a sample point located every one or two chains along the transect. The idea is to systematically obtain at least 20 sample trees per stand. If previous stand exam data are available, these may be used, but additional information may need to be collected. Large stands differing widely in aspect or frequency of wounding should be stratified into homogeneous units and each unit sampled separately.

11

Stand and Tree Characteristics Measured

Mean crop tree age—Obtain the total age of each crop tree by increment boring at breast height and adding 10 years (difference between total age and breast height age). Sum the individual ages and divide by the number of samples to obtain mean crop tree age. Stands less than 40 years old will have little or no decay.

Percentage of crop trees with wounds—Record if the crop tree has one or more wounds (>1 square inch). Include top breaks and dead tops (if below merchantable height), frost cracks, fire scars, and wounds on major exposed roots. Stand exam procedures by the USDA Forest Service, Northern Region, require the recording of stem wounds as 91 for logging damage, 96 for broken or missing tops, and 99 for checks and bole cracks. These data can be used to calculate the percentage of crop trees with wounds. Trees with conks should not be selected as crop trees. Sum the number of trees with one or more wounds and divide by the number of sample trees in the stand to obtain the percentage of trees with wounds. The method was designed for stands with more than 15 percent but less than 90 percent of the crop trees having wounds. If most of the wounds are recent (less than 10 years old), actual current decay volumes may be less than estimated. If average size of wounds exceeds 2 square feet, actual current decay volumes may be higher than estimated.

Aspect—Record the aspect of the stand. Enter "0" for northern aspects (N, NW, NE, W, or flat) or "1" for southern aspects (S, SE, SW, or E).

Optional: mean crop tree d.b.h. and mean current radial increment—Measure the d.b.h. and the last 10 years of radial growth for each crop tree. Average these for the stand. Although d.b.h. and current radial increment are not needed to estimate the percentage of decay, they may be useful in determining years for additional diameter growth to reach merchantibility.

Estimating Future Decay

The equation for estimating decay can also predict percentage of decay at any point in the future because "mean crop tree total age" is a variable in the equation. Also, the "percentage of crop trees with wounds" can be increased, especially if future stand entries will be made.

Wounding of trees during commercial thinning operations ranges between 5 and 14 percent when methods designed to reduce damage are used and between 22 and 50 percent when conventional logging techniques are used (Aho and others 1983). An increase in "percentage of crop trees with wounds" resulting from adding 25 percent for commercial thinning, could be used to project decay rates, but local knowledge of wound incidence following typical entries would yield more accurate estimates.

Wounds occurring within 10 years of stand harvest can be ignored because decay would not have sufficient time to develop. Wounding incidence would probably be less for precommercial thinning but more for overstory removals depending on the volume removed. In making decay projections, it should be assumed that wounding will increase by 1 percent every decade because of naturally caused wounds.

Board-foot (Scribner) defect percentages can be calculated for stands ≥11 inches d.b.h. by multiplying cubic-foot decay percentages by 2.7 (Aho 1977). Board-foot decay percentages are always higher than cubic-foot decay percentages because of scaling differences between cubic- and board-foot measures. Also, board-foot defect percentages include deductions for shake, frost cracks, and sound volume lost in cull logs, as well as for decay.

How To Use the Equation

Following are two examples of how to use the fir decay equation to estimate the future percentage of decay. The current estimated percentage of decay in the first stand (Powell 403) in table 1 is 1.3 percent. If this stand is grown from age 77 to 100, the future estimated percentage of cubic-foot decay is 2.2 percent. To obtain this figure, insert AG=100, WD%=47 (45+2), and AS=1 into the equation, because naturally caused wounds increase about 1 percent per decade (age 77 to age 100). For the second example, the last stand (Idaho-Ford) in table 1 will be grown from age 50 to 100 and commercially thinned at age 75. The future estimated percentage of cubic-foot decay is 2.9 percent. To get this figure, insert AG=100, WD%=40 (10+5+25), and AS=0 into the equation; 5 percent is for naturally caused wounds over five decades and 25 percent is the estimated additional wounding from the thinning. If we wanted the future estimated percentage of board-foot decay for this stand, we would multiply the cubic percentage (2.9 percent) by 2.7 to get 7.8 percent.

Stand Management

The following management recommendations are suggested for minimizing stem decay in grand fir in northern Idaho where timber production is to be optimized:

1. Manage on short rotations. Keep rotations to less than 150 years and preferably to less than 120 years of age. Decay increases considerably after 150 years.

2. Do not avoid or delay early thinning because of perceived potential decay losses. Growth increases due to thinning will outweigh decay losses in most cases. Increased vigor due to thinning will reduce Indian paint fungus infection. Thin early so that potential decay columns, should they develop as a result of wounding, will be relatively small owing to compartmentalization.

3. Select crop trees by the following criteria:
   a. At least 50 percent live crown ratio.
   b. At least 8 inches of current leader growth (to ensure release).
   c. No conks, wounds, or top damage.
   d. The best form and height.

4. Minimize wounding. Wounds can and should be prevented when thinning, doing prescribed burning, disposing of slash, or removing the overstory because of the potential losses by decay and other defects associated with injuries. Actions can be taken, both in planning and during the operation, to prevent much of this damage (Aho and others 1983, Filip and others 1983).

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The fir decay equation for Oregon and Washington was used to predict stem decay in 12 grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) stands in the Clearwater region of northern Idaho. These 12 stands represented a range in geographic and stand characteristic variation. All 12 observed decay percentages were within their associated 95-percent prediction intervals. We therefore concluded that the fir decay equation for Oregon and Washington can be used to estimate stem decay in 40- to 90-year-old grand fir stands in the Clearwater region. Information also is presented on decay biology, hazard-rating techniques, and stand management recommendations.

Keywords: Heartrot, grand fir, decay, hazard rating.

U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. Box 3890
Portland, Oregon 97208

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